Public Interest Energy Research (PIER) Program

Draft Research Roadmap

Energy, Air Quality, Water and Climate Change Co-Benefits of Renewable Power Generation and Fuels Roadmap

Draft Summary of Research Roadmap

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Abstract

The deployment of renewable power generation technologies in California, including at levels mandated by current policy, will have impacts across many different sectors and endpoints, including greenhouse gas emissions (GHG), air quality (AQ), and water resources. Shifts from traditional fuels and technologies may have unforeseen benefits or negative consequences. Some of these GHG, AQ and water impacts are fairly well characterized and understood on their own while others are not, which creates a need for additional research on GHG, AQ and water impacts themselves. In addition, integrated understandings of GHG, AQ and water co-benefits that apply to a particular technology are not well understood. No accepted methodology exists for formally evaluating co-benefits even though such analyses are essential to inform California decision makers about the full range of potential benefits and the combined GHG, AQ and water impacts of renewable energy resources. Based on a review of existing studies and available literature, interviews of stakeholders, and input received from public workshops, and on-line surveys, a roadmap has been developed identifying the state of knowledge, research gaps, and recommended research pathways to maximize and quantify energy and environmental co-benefits of using renewable power generation and fuels in California.

Introduction

Current California power generation is dominated by technologies and fuels that emit greenhouse gases (GHGs) and can negatively impact air quality (AQ) and the State's water resources. Due to various drivers, California is committed to increasing renewable energy resources (RER) for the provision of electricity in coming decades. The procurement of renewable power can have numerous and widely varying impacts on environmental endpoints that have the potential to affect human health and societal well-being in California, including GHG, AQ, and water resources. Often, the full spectrum of impacts associated with increasing RER is not as well understood as it is for conventional methods.

Many renewable sources offer co-benefits in the case of multiple positive outcomes, while others offer dis-benefits, in the case of positive impacts on one endpoint at the expense of negative impacts on other endpoints. Further, increasing RER has the potential for both additional benefits and/or unforeseen negative consequences, e.g., land-use, ecological resources, aesthetics. Because knowledge gaps regarding these co-benefits or dis-benefits exist in many areas, there is significant need for further research into the co-benefits of renewable power. Inclusion of co-benefit assessments is therefore of great importance, including the use of co-benefits analysis for optimal design and deployment of programs and policies to maximize co-benefits. Further, accurate portrayal of the full range of positive impacts can assist in addressing concerns over economic costs and can affect positions held by various stakeholders in California.

Methods

In order to assess the current state of the knowledge and establish a scope for research and development (R & D) needs regarding potential co- and dis-benefits of deploying renewable technologies and fuels in California, a comprehensive review of existing information was conducted for pertinent areas. Sources of material include, but are not limited to, peerreviewed scientific literature, technical presentations, industry reports, and government documents.

In order to meet the goal of identifying the roadmap scope with regards to relevant renewable energy pathways, including technologies and fuels, a technology assessment was conducted. Assessment areas included all aspects of bringing selected technologies to commercial deployment in California, e.g., siting of facilities, life cycle impacts, and implementation. Identified technologies and fuels, as well as relevant insights, research findings, and background information were presented at a public workshop held by the California Energy Commission with invitations to a broad range of stakeholders and experts. Issues and concerns raised by participants were used to modify the initial report and prepare a final assessment draft.

In order to meet the goal of evaluating current methods used to determine energy, AQ, GHG, and water co-benefits and identify opportunities and requirements to highlight co-benefits in California policy and programs, an analysis was conducted of current literature and relevant California legislation. A focus was given on recognizing research gaps and needs in order to improve current methods and develop novel co-benefit assessment strategies. A summary of findings was presented at the hosted workshop and participant feedback was used in the development of final methodology assessment report draft.

Additionally, to support the advancement of this research roadmap a web-based survey was developed and published on-line. Many stakeholders responded to the survey, which facilitated community critique and analyses of the knowledge gaps and research needs identified for co-benefits of renewable power generation and fuels. Feedback was sought on identifying key issues or potential conflicts relating to co-benefit opportunities and the methods with which such opportunities are addressed in California. Collected survey data was analyzed and utilized to serve as input into roadmap development. The survey was developed utilizing web-based tools available through the University of California at Irvine (UCI) via the Electronic Educational Environment (EEE). The survey was disseminated through various channels and included responses from 105 participants.

To meet the final goal of developing a roadmap identifying the state of knowledge, research gaps, and recommended research pathways to characterize and quantify energy, GHG, AQ, water and other environmental co- and dis-benefits of renewable power, the findings of previous tasks were integrated into a cohesive document outlining barriers and research gaps to the adoption of selected technologies in an environmentally sound manner. A focus was given to suggested research pathways that will assist in allowing California to maximize co-benefits of renewable technologies and fuels while avoiding any unforeseen or harmful impacts.

Results

The results of the roadmap, in terms of identified and suggested priority R & D needs for California, are presented in tabular form below (Table 1, Table 2, and Table 3). Categories include technological and fuel pathways, GHG, AQ, and water resource impacts, and co-benefits assessment and methodologies. In addition, biopower was identified as being of particular importance with regards to both potential co- and dis-benefits. Further, biopower includes a dramatic range of energy pathways, including resources, conversion pathways, enduse products, etc. As such, a separate table of biopower research gaps and R & D needs is presented in Table 3.

In order to meet the established project objectives of identifying research gaps and suggested R & D to assist California in better characterizing, quantifying, and maximizing the environmental co-benefits of renewable power generation, the following three categories of research goals were established:

Research Goals

1. Furthering the state of knowledge in selected research areas to assist in developing strategies to maximize co-benefits from the deployment of renewable power
2. Address technological barriers and research gaps to the adoption of selected technologies in environmentally sound manners
3. Improve methodologies to characterize, assess, and quantify air quality (AQ), greenhouse gas (GHG), and water co- and dis-benefits from renewable power

Technology and Fuel Advancement Research Needs

Current California power generation is dominated by fossil fuels, including a heavy reliance on natural gas. Key renewable power generation technologies that are available currently include wind, solar (photovoltaic (PV), concentrated solar power (CSP), and solar thermal power), hydropower, geothermal, and multiple biopower pathways (biomass, municipal solid waste (MSW) and biogas). In the long-term, promising renewable technologies that could have GHG, AQ and water co-benefits include those that derive energy from the ocean (i.e., wave, thermal and tidal); fuel cells operating on various resources and algae-based fuels; but these will require further technological development and are not explicitly included in the current analyses.

The varying states of technological maturity with regards to commercial deployment at-scale in California yield different foci for research needs and knowledge gaps. Research for technologies available currently or near-term should include optimized deployment strategies at the systems-level, including elucidation of strategies to reduce costs and improve efficiencies. For technologies that require further development, research goals should include advancing fundamental technological performance and evaluation of potential deployment, including demonstration projects, in California. Additionally, a thorough understanding of the State's conventional power structure is necessary to optimize renewable deployment and evaluate the impacts of displaced generation. The following priority research and development (R & D) needs were identified for technologies and fuels.

Table 1. Summary of priority R&D needs to address the knowledge gaps identified for technology and fuel advancement

Technology and Fuel Advancement Priority R & D Needs	Research Goal			GHG Impacts	AQ Impacts	Water Impacts	Term* S M L
	1	2	3				
Biopower** (see Table 3)	X	X	X	+++	+++	+++	S-M-L
Advancement of ocean energy technologies • *CA resource assessments* • *Utility-scale demonstration projects*	X	X		++	++	++	M

Advancing the technical performance of fuel cells and BOP technologies to reduce cost		X		++	+++	+++	S-M
Integrated use of fuel cell systems, e.g., TIGER station, renewable fuel, dynamic dispatch to complement wind/solar		X		++	+++	+++	S-M
RER-fuel cell integrated systems for energy storage, e.g., improve efficiencies, hydrogen yields, reliability and reduce costs • *Utility-scale demonstration projects in CA*		X		+++	+++	+++	M-L
Advancement of algae-based fuels for power generation, including technological, economic, and resource assessment	X	X		+++	++	+++	M-L
Thorough assessment of potential for CA algae fuel production and deployment	X			++	++	++	S
Demonstration of scalable commercially viable production in CA		X		+++	++	++	M-L
Designing/evaluating integrated cultivation & digestion systems • *Optimization of cultivation in waste water* • *Enhancement of digestibility/conversion rates*		X		++	++	+++	M-L
Elucidation of environmental impacts to assess co-benefits • *Life cycle GHG emissions for specific systems and pathways* • *Emission impacts for displacement and direct impacts for CCS* • *Water resource impacts for usage and quality*	X			++	++	++	S-M
Detailed grid modeling projecting the evolution of the California power system (e.g., load demands, dynamics)	X		X	+	+	+	S
Detailed evaluation of complimentary and/or back-up generation required for various renewable penetrations	X			+	++	+	S-M
Accurate assessment of the environmental impacts of natural gas production, T&D, and use. e.g., GHG footprint, water impacts of non-traditional gas reserves	X			++	+	+	S
Support the co-deployment of additional low impact complementary strategies, e.g., smart grid, control, energy storage	X	X		+++	+++	++	M-L
Advancement of energy storage in utility applications to support renewable deployment and integration • *Demonstration projects of integrated commercial/distributed scale applications*	X	X		++	++	+	S-L
Support progress of energy storage technologies with the potential for significant capacity additions in CA, e.g., reduced costs		X		++	++	+	S-M
Identification and analysis of opportunities for CA energy storage deployment	X			++	++	+	S

* S = short, M = medium, L = long
** Due to the breadth of issues and significance of potential co-benefits and dis-benefits of biopower, a separate table with multiple R&D needs has been developed

Environmental Impacts (GHG, AQ, Water) of Technologies and Fuels

The use of renewable power and fuels can have numerous and widely varying impacts on environmental endpoints that have the potential to affect human health and societal well-being in California, including GHG, AQ and water resources. Some technologies have direct impacts in some areas, e.g., direct emissions from biopower systems, direct water consumption for cooling CSP plants, while others do not. However, all renewable technologies and fuels impact GHG, AQ, and water on a life cycle basis, and evaluation of impacts must be conducted using a life cycle analyses (LCA) scope. The following research needs (Table 2) were identified and prioritized for each impact area given high priority in this assessment in order to more fully understand and assess potential perturbations from renewable deployment and to elucidate and pursue opportunities to maximize benefits in the support of co-benefits.

Table 2. Summary of priority R&D needs to address the knowledge gaps identified for environmental impacts of technologies and fuels

Environmental Impacts (GHG, AQ, Water) Priority R & D Needs	Research Goals			GHG Impacts	AQ Impacts	Water Impacts	Term* S M L
	1	2	3				
Biopower** (see Table 3)	X	X	X	+++	+++	+++	S-L
Updated GHG LCA for renewable pathways with specific technology and CA boundaries/ inputs	X		X	+++	+	+	S
Accurate assessment of GHG impacts of natural gas recovery, storage and transmission (esp. non-traditional)	X			++	+	+	S
GHG emission impacts of the dynamics of grid operations with high renewable use and complementary technologies	X		X	+++	++	+	S
Localized AQ impacts across a broad spectrum of potential future renewable scenarios, e.g., horizons, policies	X				++		S
Impacts of systems-level integration of renewable power (e.g., dynamic emission impacts, low-emission back-up generation)	X		X	+++	+++	++	S
Enhanced data availability to support comprehensive, accurate AQ assessment of power plant impacts	X		X		++	++	S
Low-emissions complementary technologies to support grid dynamics with high renewable use		X		++	+++	+	M
Detailed assessment, including economic valuation, of health impacts from reducing pollutant exposure	X		X		++		S-M
Improved understanding and assessment of power generation impacts on California water resources (e.g., inventories, LCA)	X		X			+++	S

Detailed evaluation of CA power plant impacts on water resources, e.g., value of externalities from alternatives	X		X			++	S
LCA water impacts of renewable energy technologies, i.e., increased characterization of up- and downstream processes	X					++	S-M
Improved performance of advanced cooling technologies, i.e., dry (air) and hybrid cooling systems • *Cost reduction/efficiency improvements* • *Enhanced performance during non-ideal conditions* • *Deployment/evaluation of CA demonstration projects*		X		+	+	+++	S-M
Improved cost/benefit analyses for advanced cooling accounting for the full range of benefits	X			+	+	+++	S
Characterization and improved understanding of minimization strategies for air emissions from cooling activities	X				+	+	S-M
Evaluation of the use of degraded resources for power generation, e.g., benefits, costs, emissions	X				+	++	S

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Biopower

Biopower is important to California's renewable energy portfolio and offers the potential for significant GHG reductions, particularly if feedstocks arise from waste streams. However, unlike some renewable power resources, certain pathways emit pollutants directly and have life-cycle emissions that could negatively impact AQ. In addition, biopower pathways can have both positive and negative water resource impacts. The wide ranging, sometimes conflicting impacts require caution and careful assessment when considering widespread adoption of biopower due to associated implications for localized AQ and freshwater resources. Therefore, significant adoption of biopower necessitates detailed and regionally defined analyses to better understand pathways with the highest co-benefits. The following R & D needs (Table 3) were identified to assist in utilizing the State's bio-resources in environmentally sound manners to avoid harmful impacts while maximizing significant potential co-benefits.

Table 3. Summary of biopower priority R&D needs to address the knowledge gaps identified

Priority Biopower R & D Need	Research Goal			GHG Impacts	AQ Impacts	Water Impacts	Term* S M L
	1	2	3				
Detailed assessment of CA biopower resources, e.g., suitable waste streams, energy crops, other bio-resource opportunities, properties, spatial distribution, amount, …	X			+	+	+	S

Comprehensive evaluation to identify preferred uses and strategies for maximum co-benefits of CA resources, e.g., costs/benefits between pathways, sectors, technologies	X		X	+++	+++	+++	S-M
Identify and address regulatory, statutory, and utility interconnection impediments to deployment of biopower	X			+	+	+	S
Develop assessment methodologies to value the broad range of biopower benefits and dis-benefits	X		X	++	++	++	S
Enhanced characterization of potential co- and dis-benefits of emerging advanced conversion devices e.g., FC, micro-turbine, gasification	X			+	+	++	S-L
Deployment of commercial scale biomass gasification with CHP demonstration projects		X		++	++	++	M-L
Improved efficiencies and reduced costs for low-emissions conversion equipment (e.g., fuel cells, turbines) operating on renewable fuels		X		+	++	+	S-M
Detailed LCA of biopower specific to CA, including range of pathways, technologies, etc.	X			+++	+	+	S-M
Assessment and inclusion of off-set GHG emissions in estimates in CA policy impacts, e.g., flaring, controlled burning	X			++	+	+	S
Analyses of current/emerging bio-resource e.g., waste water treatment, landfill, agriculture & forest waste	X			++	+	+	S
Development/commercial demonstrations of no- and low-NO_x systems, e.g., FC, pipeline injection, microturbine		X		++	+++	++	S-M
Detailed regional/local assessment of impacts with spatial resolution across range of future year scenarios, pathways, sources, magnitudes	X			+	+++	+	S
Hydrogen enriched fuel gas for lean burn engine application		X		+	++	+	S
Development of advanced pollutant control technologies for traditional conversion devices		X		+	++	+	S
Investigation of hazardous air pollutant emissions and strategies to mitigate impacts	X	X			+		S
Novel permitting procedures to support deployment in regions with poor AQ. Should incorporate offset emissions	X		X	++	+++	++	S-M
Detailed assessment of water usage, i.e., withdrawal and consumption, from various biopower pathways	X		X			++	S
Assessment and development of strategies to minimize water usage, e.g., advanced conversion and cooling	X	X				++	S-M
Elucidation of potential water quality impacts, e.g., liquid discharge from gasification, contamination, leachate	X					++	S-M

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Co-benefit Assessment Methodologies

At the present, assessment of co-benefits from renewable power is limited by the lack of a comprehensive structure that allows for assessments across multiple environmental and energy impacts. Thus, the development of standardized and accepted methodologies that attempt to take a more holistic view of co- and dis-benefits are needed in assisting California decision-makers to maximizing benefits and minimizing costs. The valuation of co-benefits is important in accurately valuing the benefits provided by renewable power generation. For example, assigning value to the various possible co-benefits and dis-benefits that may result from GHG mitigation strategies may be important in determining whether the policy of GHG mitigation is effective economically. Economic valuation of co-benefits is multifaceted and various methodologies have been utilized in attempts to quantify impacts. Valuation of co-benefits and dis-benefits can be challenging, particularly if values are being assessed with regards to future year assumptions. Further, the values placed on certain socioeconomic impacts vary from individual to individual, requiring transparent methodologies and assumptions that can examined rigorously.

The development of new and advanced methodologies for assessing and quantifying the co-benefits associated with the utilization of renewable technologies and fuels is complex and far reaching, spanning a vast range of sectors, regions, and endpoints. Assessment methodologies already in use will need to be updated and improved to account for new data and the evolution of nearly all aspects of power generation and use. In addition, novel methodologies will be needed to tie individual assessments into more comprehensive structures that allow for accurate valuation of all impacts. Considerations should include standardized valuation methodologies to facilitate comparison, considerations of impacts in areas outside of the state when relevant, interrelated impacts associated with climate change, situations and any other additional energy or environmental endpoints of concern. The following R & D needs are associated with the development of appropriate methodologies to assist in the identification and valuation of co-benefits of renewable power generation.

Table 4. Summary of co-benefit assessment methodology priority R&D needs to address the knowledge gaps identified

Priority R & D Need	Research Goal			GHG Impacts	AQ Impacts	Water Impacts	Term* S M L
	1	2	3				
Novel, enhanced methodologies for identifying and valuing the full range of co-benefits • *Proper methodologies for individual assessment areas* • *Standardized weighting methodologies for impacts* • *Valuation of full costs and benefits of technologies/pathways*	X		X	++	++	++	S-L
Assessment of other environmental/energy impacts e.g., land-use, ecological for co-benefits	X		X				S-M
Enhanced data availability and reliability to support comprehensive methodologies	X		X	+	+	+	S
Detailed evaluation of CA policies/programs from a co- and dis-benefits perspective	X			++	++	++	S
Identification/assessment of sectors/ opportunities for high co-benefits, e.g. ports, SJV	X			++	++	++	S
Consideration of regional level interactions and impacts (e.g., out-of-state vs. in-state impacts)	X		X	+	+	+	S

Improve permitting procedures for renewable projects with potential for high co-benefits	X			++	++	++	S-M
Assessment of future siting methods to locate renewable projects with maximum co-benefits	X			+	++	++	S-M
Increased understanding of impacts and interrelationships of climate change on co-benefit impact categories. E.g., : • *Temperature impacts on generator efficiencies* • *Temperature impacts on load demands* • *Impacts of climate change on respiratory health*	X		X	++	++	+++	S-L
Evaluation of ancillary health impacts of reducing GHG under AB 32, including non-AQ	X		X	++	++	++	S-M
Identification of effective approaches for the mitigation, avoidance, and adaption to impacts	X			++	+++	+++	S-L
Biopower** (see Table 3)	X	X	X	+++	+++	+++	S-L

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